1479 Issued March 12, 1913.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,

D. W. MAY, Special Agent in Charge.

Mayaguez, September, 1912.

Bulletin No. 12.

LIME-MAGNESIA RATIO AS INFLUENCED BY CONCENTRATION.

BY

P. L. GILE,
CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

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PORTO RICO AGRICULTURAL EXPERIMENT STATION.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,
Mayaguez, P. R., September 12, 1912.

SIR: The study of the basal relations of the elements in plant production must result in an advancement in the science of agriculture. We have been studying since the beginning in this branch of endeavor from effect; we are slowly working back to cause. Additional data as to basic principles in the handling of soils in the production of plants are greatly needed. Soils, especially those elements therein which serve as plant food, and their relations to one another, merit the closest study, that our practical efforts may be guided by facts and not by guesswork. This manuscript, on the Lime-Magnesia Ratio as Influenced by Concentration, by P. L. Gile, chemist of the station, is another step in that direction, and I recommend that it be published as Bulletin No. 12 of this station.

Respectfully,

D. W. MAY,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON,
Secretary of Agriculture.

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LIME-MAGNESIA RATIO AS INFLUENCED BY CONCENTRATION.

INTRODUCTION.

Some years ago Loew advanced the theory that plants make their maximum growth—other conditions, of course, being favorable—when the available lime and magnesia are present in a certain ratio to each other, the optimum ratio for most plants being about 2 of lime to 1 of magnesia. The details of the theory and a partial list of references are given in a circular [1] of this station and in numerous other publications.[2]

Since this theory was first enunciated in 1892 [3] it has been subjected to much criticism, both favorable and adverse. Investigators have tested the theory by growing various plants in soil and water cultures containing lime and magnesia in different ratios. In some cases the results have been such as to lend credence to the theory; in other cases the results have been negative.

Many small pot experiments have been carried on by Loew and his colleagues in Japan, adding compounds of lime and magnesia to different soils to alter the ratios of these elements already present. The results of these experiments have been such as to confirm the theory.[4]

The results of two series of pot experiments by Meyer,[5] who applied lime and magnesium carbonate to various soils, seemed to show that the maximum yield is not dependent upon a definite ratio of lime to magnesia. The most exhaustive series of pot experiments on this subject have been carried out by Lemmermann, Einecke, and Fischer.[6] They experimented with six different soils, growing eight different plants, for two to three successive years, and concluded that no special ratio of lime to magnesia in the soil was particularly favorable for the growth of plants.

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[1] Porto Rico Sta. Circ. 10.

[2] Loew, O., and D. W. May, U. S. Dept. Agr., Bur. Plant Indus. Bul. 1 (1901). Loew, O., U. S. Dept. Agr., Div. Veg. Physiol. and Path., Bul. 18 (1899).

[3] Loew, O., Flora, 75 (1892), p. 368.

[4] See reports in Vol. I of Bul. Imp. Cent. Agr. Expt. Sta. Japan, and Vols. IV, V, VI, VII of Bul. Col. Agr. Tokyo Imp. Univ.

[5] Meyer, D., Landw. Jahrb., 33 (1904), p. 371; 39 (1910), Sup. 3, p. 254.

[6] Lemmermann, O., A. Einecke, H. Fischer, Landw. Jahrb., 40 (1911), No. 1-2, p. 173.

Bernardini and Corso [1] and Bernardini and Siniscalchi [2] substantiated the theory of Loew in pot experiments with maize, rye, and beans and in water cultures with rye, corn, barley, and wheat. Voelcker,[3] from rather inconclusive experiments, concluded that the growth of wheat was best at the ratio of 1:1. Dojarenko [4] concluded that the theory is not tenable, as many Russian soils containing a great excess of lime over magnesia are benefited by liming.

Aside from the above experiments there have been many soil analyses indicating that fertility or nonfertility was attributable to favorable or unfavorable ratios of lime to magnesia.[5] In considering a complex system such as the soil, however, such observations or conclusions are merely hypothetical.

The contradictory results in many instances appear to be due to failure to take into consideration the fact that two factors are being dealt with, the soil and the plant. When the carbonates or sulphates of lime and magnesia are added to the soil to alter their ratio, not only are the available quantities of these nutrients changed, but other changes in the soil are brought about, the effect of which it is impossible exactly to estimate or control. For instance, on adding calcium carbonate to a neutral soil devoid of carbonate the reaction is changed to slightly alkaline. This has a direct effect on the adaptability of certain plants to this soil.[6] The bacterial life in the soil is also changed,[7] as certain bacteria thrive best in a more or less alkaline medium.[8] The availability of the other soil nutrients—phosphate, potash, and nitrogen—is changed at the same time. There is also the added effect of the action of lime on the physical or mechanical condition of the soil.

One of the strongest factors in determining the yield of certain plants is the reaction of the soil; hence in applying magnesia or calcium carbonate a certain portion of their action is to be attributed to the degree of alkalinity produced. This effect has been studied by Meyer,[9] who found that ground magnesite, ground marble, pre-

[1] Bernardini, L., and G. Corso, Staz. Sper. Agr. Ital., 41 (1908), p. 191.

[2] Bernardini, L., and A. Siniscalchi, ibid., 42 (1909), p. 369.

[3] Voelcker, A., Jour. Roy. Agr. Soc. England, 70 (1909), p. 379; 71 (1910), p. 346.

[4] Dojarenko, A., Zhur. Opytn. Agron. (Russ. Jour. Expt. Landw.), 4 (1903), p. 183.

[5] Snowden, R. R., Rural Californian, 34 (1910), p. 358.

[6] Wheeler, H. J., et al., Rhode Island Sta. Rpts. 1893, pp. 224–252; 1894, p. 152; 1895, p. 205; 1896, p. 242; 1897, p. 202; 1898, p. 144; 1899, p. 171; 1900, p. 293. Coville, F. V., U. S. Dept. Agr. Bur. Plant Indus. Bul. 193.

[7] Lemmermann, O., and H. Fischer, Landw. Jahrb., 40 (1911), No. 1–2, p. 244.

[8] When calcium sulphate or magnesium compounds are applied instead of calcium carbonate, there is the reciprocal effect of the bacteria on the salt applied. An illustration of this occurred here. An alkaline soil from the Santa Rita district was treated with gypsum. The gypsum improved the physical condition and reaction of the soil, but nevertheless the growth of rice and tomatoes in the treated soil was less than in the check without gypsum. This effect was found to be due to the action of sulphate-reducing bacteria forming hydrogen sulphid from the calcium sulphate. (Reported by Loew et al. in Centbl. Bakt. [etc.], 29 (1911), No. 23–25, p. 674.)

[9] Meyer, D., Landw. Jahrb., 33 (1904), p. 371. Similar results were arrived at by Kossovich and Althausen, Trudy Mendelyevsk. Syezda Obshch. i Prikl. Khim., 1 (1907), pp. 490; abs. in Zhur. Opytn. Agron. (Russ. Jour. Expt. Landw.), 10 (1909), No. 5, p. 693.

cipitated calcium carbonate, precipitated magnesium carbonate, and burnt lime vary in the reaction they induce.

Thus a mixture, for instance, of precipitated calcium and magnesium carbonates will induce a reaction which is different from that induced by either alone. In some of the experiments noted above there seems to have been an error due to not taking these facts into consideration.[1]

The theory has also been tested by growing plants in sand and water cultures. May[2], in trials with oats, wheat, cowpeas, and tobacco in sand cultures, using concentrated solutions of calcium and magnesium nitrate, obtained results confirming the theory. Loew, in a water-culture experiment with barley, found the ratio 1 : 1 better than 0.4 : 1. Only two ratios were tried, however, and only two plants were grown at each ratio.[3] Aso[4] and Sirker[5], in experiments with a variety of plants in water and sand cultures, obtained results confirming the theory.

Konovalov,[6] using water and sand cultures, found that the yield of wheat, white lupines, millet, and oats was largely dependent on the absolute amount of lime in the solution. With wheat the highest yields were obtained with lime-magnesia ratios of 3.3 : 1, 6.7 : 1, and 13 : 1. With a ratio of 26.6 : 1 there was a marked decrease. With oats the best yield was 6.7 : 1. These results contradict Loew's theory to some extent, but agree with it in showing a depression when the lime greatly exceeds the magnesium.

It is apparent from the results of the various experiments that the question whether there is a definite ratio of lime to magnesia at which plants grow best is an unsettled one. Recent advances in our knowledge of plant physiology seem to increase the complexity of the subject in showing relations that exist between a great number of salts and also in throwing new light on the relations existing between the cell and various combinations of salts.

Without attempting a recapitulation of all the work on this subject, it appears that some salts which are essential in the nutrition of the plant are injurious when present in a pure solution.[7] The

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[1] C. G. Hopkins (Soil Fertility and Permanent Agriculture, Boston, 1910, p. 170), in an experiment on the injurious effect of magnesium, apparently was led to an erroneous conclusion by the use of precipitated magnesium carbonate (that precipitated $MgCO_3$ was used was learned from a personal communication) which is a basic salt strongly alkaline in reaction. This result, then, instead of showing the injury from too much magnesium, merely shows injury from too strong an alkalinity or from that particular salt of magnesium.

[2] Loew, O., and D. W. May, U. S. Dept. Agr., Bur. Plant Indus. Bul. 1, pp. 47–50.

[3] Loew, O., Landw. Jahrb., 35 (1906), No. 4, p. 527.

[4] Aso, K., Bul. Col. Agr. Imp. Univ., Tokyo, 4 (1902), No. 5, p. 361.

[5] Sirker, J. N., Jour. Col. Agr. Imp. Univ., Tokyo, 1 (1909), No. 2, p. 183.

[6] Konovalov, I., Dnevn. XII. S'ïezda Russ. Est.-Isp. i Vrach [Moscow], 1910, No. 9, p. 391; abs. in Zhur. Opytn. Agron. (Russ. Jour. Expt. Landw.), 11 (1910), No. 1, p. 107; Zentbl. Agr. Chem., 39 (1910), p. 152.

[7] Benecke, W., Ber. Deut. Bot. Gesell., 25 (1907), p. 322; Bot. Ztg., 2. Abt., 62 (1904), p. 114. Osterhout, W. J. V., Bot. Gaz., 42 (1906), p. 127; 44 (1907), p. 259; 48 (1909), p. 98; Jahrb. Wiss. Bot. [Pringsheim], 46 (1908), p. 121.

toxicity of the various salts is different for different species of plant and animal life. For instance, of the chlorids of sodium, potassium, magnesium, and calcium, calcium chlorid is the most toxic for *Baccillus subtilis* [1] and the least toxic for wheat.[2]

It was shown by Kahlenberg and True [3] that this toxicity of various salts is a specific property of the ions. It has also been shown for plant and lower animal life that a mixture of two salts, both of which are toxic in pure solutions, is much less injurious than either one alone, or that there is an antagonistic action of the salts. The strength of the antagonism varies between the different bases.

Loew showed the toxicity of magnesium salts was lessened by addition of calcium salts. Osterhout [4] showed that for plants there was an antagonistic action between sodium and potassium, sodium and ammonium, sodium and magnesium, sodium and calcium. Also nonnutritive salts, as those of calcium and aluminum, in some cases diminish the toxicity of pure or mixed solutions.[5] Lipman has shown the antagonism between $CaCl_2$ and KCl for *B. subtilis*,[6] and McCool, in experiments with peas found the following antagonisms: Ca *vs.* Ba, Fe, K, Mg, Mn, Na, NH_3, Sr; K *vs.* Sr.; Na *vs.* Mn; Na *vs.* Sr.[7]

As the toxicity of a pure solution is diminished by the addition of a second salt, so is the toxicity of certain mixtures diminished by the addition of a third or fourth salt. By addition of various salts a mixture known as a balanced solution (i. e., one which is no more injurious than distilled water) can finally be obtained. Such a balanced solution, however, is not necessarily a complete nutrient solution, although some complete nutrient solutions are physiologically balanced.

Various theories have been advanced to explain the toxicity of pure salt solutions and the reduction of their toxicity by the addition of other salts. Loew explained the action of calcium in diminishing the toxicity of magnesium salts by the assumption that in the cell the nucleo-proteids exist in combination with calcium, and the presence of sufficient calcium prevents magnesium from being substituted in these compounds. The action of magnesium in reducing the toxicity of an excess of calcium he attributes to the fact that magnesium serves to transport the phosphoric acid and in the absence of sufficient magnesium the phosphoric acid is fixed by the calcium and the cell suffers from phosphoric starvation. The above theory

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[1] Lipman, C. B., Bot. Gaz., 48 (1909), p. 105.
[2] Magowan, F. N., Bot. Gaz., 45 (1908), p. 45.
[3] Kahlenberg, L., and R. H. True, Bot. Gaz., 22 (1896), No. 2, p. 81.
[4] Osterhout, W. J. V., Jahrb. Wiss. Bot. [Pringsheim], 46 (1908), p. 121.
[5] Osterhout, W. J. V., Bot. Gaz., 44 (1907), p. 259.
[6] Lipman, C. B., loc. cit.
[7] McCool, M. M., Science, n. ser., 33 (1911), p. 339.

explains the antagonism between calcium and magnesium, but does not explain the antagonism existing between other bases.

A recent explanation of the antagonistic action of salts is that proposed by Nathansohn.[1] Assuming with Loeb that there is a certain normal salt content of the protoplasm at which it functions, he holds that in a pure salt solution the ions penetrate the protoplasm and drive out other ions; thus the salt content of the protoplasm becomes normal. In a mixture of two salts, however, the added salt displaces to a certain extent the other, and the salt content approaches more nearly the normal content. There are certain other facts which substantiate this view. The cell plasma is colloidal in nature and in common with other colloids has a great power for absorption of salts. It has been shown by Koch [2] that the precipitation of the colloid lecithin by pure solutions of certain salts can be prevented by the addition of other salts, i. e., there is an antagonistic action between the ions in respect to the precipitation of colloids.

The opinion of many investigators is that the antagonistic action of the various salts is to be ascribed to the effect they have on the colloidal condition of the cell proteids.

The above hypothesis of the necessity of preserving a certain balance in the salt content of the colloidal plasma does not, of course, explain all the facts observed in the action of salts in plant and animal cells.

For a more complete knowledge of the subject we must know more concerning the regulatory power of the cell in taking up the mineral nutrients. From the work of Meurer [3] and Nathansohn [4] it is apparent that cells are selective in their absorption of ions; that they can check osmosis before a balance is reached between the solutions within and without the cells; and that absorption of salts does not increase proportionately with increase in concentration of the outside solution. This latter point is also confirmed in the work of True and Bartlett.[5] If this regulatory power of the cell be great enough, the plant is more or less independent of the composition of the solution in which it grows.

The question whether there is a certain ratio of lime to magnesia at which plants grow best is, then, a physiological one, that in some respects can be tested better by growing plants in nutrient solutions than in soil cultures. In the nutrient solution the effect of the nutrients on the plant is more readily shown. In soil cultures, as previously pointed out, many changes are produced when we add lime or magnesia, and it can not always be told whether the increase in

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[1] Nathansohn, A., Der Stoffwechsel der Pflanzen, Leipzig, 1910, pp. 113–114.
[2] Koch, W., Ztschr. Physiol. Chem., 37 (1903), p. 181.
[3] Meurer, R., Jahrb. Wiss. Bot. [Pringsheim], 46 (1909), p. 503.
[4] Nathansohn, A., Jahrb. Wiss. Bot. [Pringsheim], 38 (1902), p. 241; 39 (1904), p. 607; 40 (1904), p. 403.
[5] True, R. H., and H. H. Bartlett, U. S. Dept. Agr., Bur. Plant Indus. Bul. 231.

the assimilable lime and magnesia is the factor influencing the yield or whether it is some secondary action of the salt upon the soil. With the idea in view of finding out first the effect of the ratio on the plant, without the disturbing factors introduced by the soil, a series of nutrient solutions were tried with different ratios of lime and magnesia.

EXPERIMENTS.

CONDUCT OF THE EXPERIMENTS.

The experiments here reported were made with upland rice, a plant suited for water cultures and better adapted to this climate than wheat. Seed was secured from a neighboring planter from rice grown in Porto Rico.

The water cultures were conducted in glass jars of 550 cubic centimeters capacity, fitted with perforated paraffined stoppers, in which the seedlings were supported by cotton. The seeds were germinated on a paraffined wire netting on the surface of distilled water. When the plumules were about 1 inch long four seedlings were transferred to each of the culture jars. Seedlings were selected with the greatest care, so that each lot should be equal in every other lot in respect to length of plumule, radicle, and size of seed, although all the seedlings in a single lot were not necessarily equal. Distilled water was used in making the culture solution, which was renewed every four days. The plants were grown in the culture solution for 40 days, except in the last four experiments (p. 19), in which they were grown 50 days. At the end of this time the plants were cut and the green weight of the tops taken. Later the air-dried and oven-dried weights were obtained and also the oven-dried weight of the roots.

A nutrient solution of the following composition was used in all the experiments:

	Parts per 100,000.
Potassium nitrate (KNO_3)	10. 71
Potassium phosphate (KH_2PO_4)	7. 14
Sodium nitrate ($NaNO_3$)	21. 43
Sodium sulphate (Na_2SO_4)	3. 15
Iron sulphate (Fe_2SO_4)	1. 61
Hydrochloric acid (HCl)	0. 16

To this nutrient solution varying amounts of calcium and magnesium chlorids were added. The above nutrient solution differs from the ordinary culture solution in having a small amount of acid and a larger content of iron than usual, but gave a most satisfactory growth of rice. At first the nutrient solution containing the conventional few drops of ferric chlorid and no acid was tried, without success; in about 10 days the leaves became chlorotic and the plants died. Additions of ferrous sulphate, however, brought back the normal green

to the leaves. The addition of a small amount of acid to the solution also appeared beneficial. Trials were then made of varying amounts of acid and ferrous sulphate, separately and in conjunction, and later the four combinations of acid and iron which appeared best were tested quantitatively, with the following results:

Test of hydrochloric acid and ferrous sulphate in nutrient solution.

Content of HCl and $FeSO_4$ in nutrient solution.	Average green weight per plant.
Parts per 100,000.	*Grams.*
0.16 HCl+0.81 $FeSO_4$......	1.73
0.32 HCl+0.81 $FeSO_4$......	1.94
0.32 HCl+1.61 $FeSO_4$......	2.01
0.16 HCl+1.61 $FeSO_4$......	2.19

The tests showed that the plants given the nutrient solution containing 1.61 grams of ferrous sulphate and 0.16 gram of hydrochloric acid developed best; hence these proportions were used.[1]

PLAN OF THE EXPERIMENTS.

The main purpose was to determine whether there is a definite ratio of the bases, lime and magnesia, at which the plants grow best when the lime and magnesia are present as chlorids, and to see whether the effect of the ratio would be evident at all concentrations.

It was thought better to study more particularly the effect of the ratios at different concentrations, since the influence of the concentration has not been studied by previous investigators. To determine this the calcium chlorid and magnesium chlorid were added to the nutrient solution in such amount that all the jars in a series would contain the same amount of chlorin, but varying ratios of lime to magnesia; hence, the only difference between the different lots of the same series lay in the lime-magnesia ratio and a difference in the concentration which was so small as to be without apparent effect. Five ratios of CaO to MgO were tried in each series, namely 10:1, 5:1, 1:1, 1:5, 1:10. Several of these series were run at different concentrations of the calcium and magnesium chlorid. As it was impossible to run all the series of different concentrations at the same time, and as the growth varies greatly according to seasonal conditions, a check lot with a small amount of $CaCl_2$ and $MgCl_2$ was run in each series so that there would be some basis of comparison between the experiments with different concentrations.

In addition to the above experiments with different ratios of the bases a series of jars was tried to see whether the $MgCl_2$ or the $CaCl_2$

[1] The demand of rice for a nutrient solution with a slightly acid reaction is interesting in connection with the depression observed in Hawaii and Japan on liming rice land.

is the more toxic when a small amount of the other salt is present. This was tried with the salts present in parts per 100,000 and with them present in equivalent molecular quantities. A series was also tried with a fairly concentrated solution of calcium chlorid and increasing amounts of magnesium chlorid, so that not only the lime-magnesia ratio changed but also the concentration of the chlorin ion and the total salt concentration. A similar series with a concentrated solution of magnesium chlorid was grown.

In the following work the ratio of CaO to MgO rather than the ratio of Ca to Mg was used, since the results of previous work on this subject are so expressed.

THE RELATIVE TOXICITY OF CALCIUM CHLORID AND MAGNESIUM CHLORID IN THE PRESENCE OF ALL THE OTHER NUTRIENTS.

In this experiment the toxicity of 50 and 90 parts per 100,000 of $CaCl_2$ in the presence of 5 parts of $MgCl_2$ was compared with toxicity of 50 and 90 parts per 100,000 of $MgCl_2$ in the presence of 5 parts of $CaCl_2$. The effect of $CaCl_2$ and $MgCl_2$ were also compared in equivalent molecular concentrations. The combined concentration of all the other salts KNO_3, KH_2PO_4, $NaNO_3$, Na_2SO_4, and HCl was the same as that used in all the following experiments, namely 44.2 parts per 100,000.

The results are given in the following table:

Comparative toxicity of $CaCl_2$ and $MgCl_2$ in presence of all other nutrients.

Composition of solution.				Growth of plants.				
$CaCl_2$ in solution.	$MgCl_2$ in solution.	Gram-molecules $CaCl_2$ in solution.	Gram-molecules $MgCl_2$ in solution.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.
Parts per 100,000.	*Parts per 100,000.*				*Grams.*	*Grams.*	*Grams.*	*Grams.*
5.0	5.0	....	....	16	57.69	6.86	2.40	9.26
50.0	5.0	....	....	15	47.24	4.74	1.69	6.43
90.0	5.0	....	....	13	23.86	3.28	1.03	4.31
5.0	50.0	....	....	16	41.10	5.27	1.75	7.02
5.0	90.0	....	....	12	20.99	2.99	1.04	4.03
5.0	4.3	$\frac{4.504}{10000}$	$\frac{4.504}{10000}$	16	57.26	6.87	2.49	9.36
50.0	4.3	$\frac{45.04}{10000}$	$\frac{4.504}{10000}$	15	29.05	3.80	1.36	5.16
90.0	4.3	$\frac{81.08}{10000}$	$\frac{4.504}{10000}$	6	12.90	1.77	.63	2.40
5.0	42.9	$\frac{4.504}{10000}$	$\frac{45.04}{10000}$	16	49.41	6.05	2.10	8.15
5.0	77.2	$\frac{4.504}{10000}$	$\frac{81.08}{10000}$	15	31.82	4.05	1.39	5.44

The solutions containing 50 and 90 parts of $CaCl_2$ gave about the same yield as the solutions with 50 and 90 parts of $MgCl_2$. In the solutions containing $\frac{45.04}{10000}$ and $\frac{81.08}{10000}$ gram-molecules of $CaCl_2$ the yield was much lower than in solutions of $\frac{45.04}{10000}$ and $\frac{81.08}{10000}$ gram-

molecules of $MgCl_2$. Hence it appears that in the presence cf all the other nutrients, $CaCl_2$ and $MgCl_2$, in equal percentage concentrations, are about equal in their toxic action on rice, but that in equivalent molecular quantities $CaCl_2$ is the more toxic. For most plants $MgCl_2$ is much more toxic than $CaCl_2$.

The extent to which the toxicity of either of these two salts is dependent upon the amount of the other and the composition of the nutrient solution in general can be well seen in the table above as well as in the following tables. In the solution containing 50 parts of $CaCl_2$ and 5 parts of $MgCl_2$ the yield was 6.43 grams; and in the solution containing 50 parts of $CaCl_2$ and 4.3 parts $MgCl_2$ the yield was 5.16 grams. Also the solution with 90 parts $CaCl_2$ and 5 parts $MgCl_2$ gave 4.31 grams, while the solution with 90 parts $CaCl_2$ and 4.3 parts $MgCl_2$ gave 2.4. This shows how much the toxicity of the $CaCl_2$ is dependent on the amount of $MgCl_2$ present. That the depressions where there were only 4.3 parts $MgCl_2$ present were not due to a deficiency in the amount of magnesium necessary for the plant can be seen from the fact that the solutions of 5 parts $CaCl_2$ and 5 parts $MgCl_2$ gave the same yield as 5 parts $CaCl_2$ and 4.3 parts $MgCl_2$.

THE EFFECT OF SMALL ADDITIONS OF CALCIUM CHLORID OR MAGNESIUM CHLORID TO A SOLUTION CONTAINING A LARGE AMOUNT OF THE OTHER SALT.

To observe further the effect of small additions of $CaCl_2$ or $MgCl_2$ to a concentrated solution of the other, two series of experiments were made the results of which are given in the tables below.

Effect of small additions of $MgCl_2$ to a solution containing much $CaCl_2$.

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2$+$MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yields taking that with 4.3 parts $MgCl_2$ as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
90.0	4.3	94.3	138.5	24.9:1	10	5.61	1.10	0.32	1.42	100
90.0	5.0	95.0	139.2	21.4:1	10	6.65	1.25	.34	1.59	112
90.0	7.0	97.0	141.2	15.3:1	11	9.04	1.64	.47	2.11	148
90.0	10.0	100.0	144.2	10.7:1	14	13.12	2.27	.62	2.89	204
5.0	5.0	10.0	54.2	....	16	22.50	3.44	1.20	4.64	....

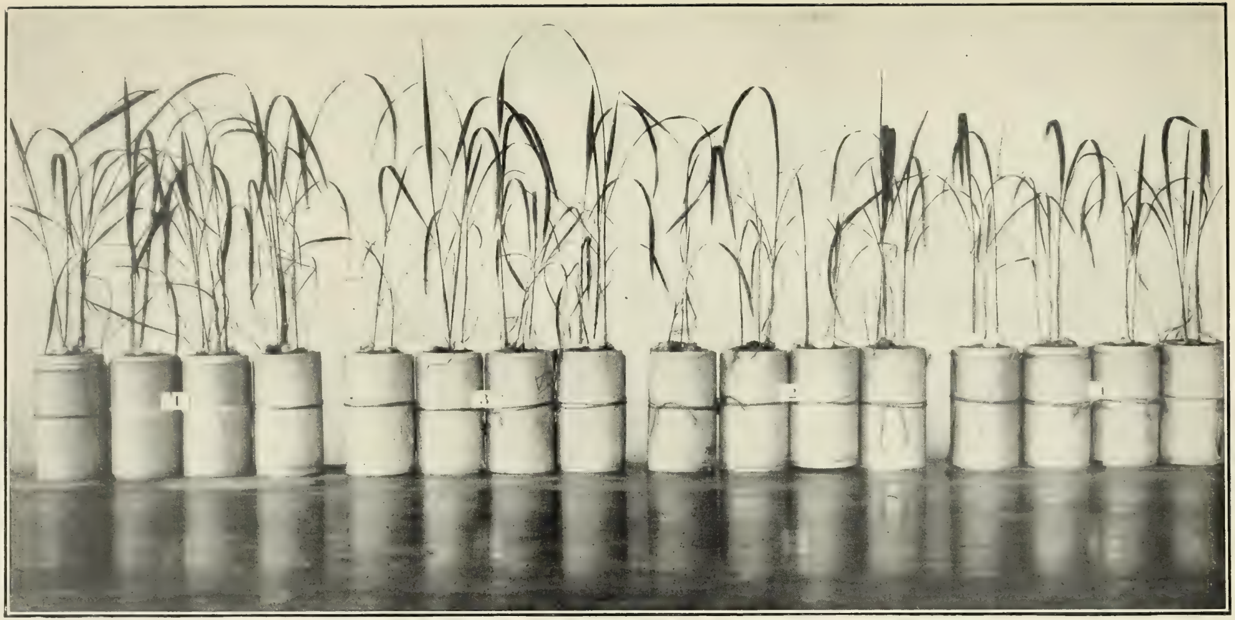
Effect of small additions of $CaCl_2$ to a solution containing much $MgCl_2$.

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2$+ $MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yield, taking that with 4.3 parts $CaCl_2$ as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
4.3	90.0	94.3	138.5	1:17.6	7	3.46	0.69	0.17	0.86	100
5.0	90.0	95.0	139.2	1:15.1	6	3.51	.71	.16	.87	101
7.0	90.0	97.0	141.2	1:10.8	5	5.51	1.11	.28	1.39	161
10.0	90.0	100.0	144.2	1:7.6	9	4.50	.93	.24	1.17	137
5.0	5.0	10.0	54.2	....	16	15.13	2.57	.67	3.24	....

It will be seen that the results substantiate those given in the table on page 15, in showing that in a solution containing a relatively large amount of either $CaCl_2$ or $MgCl_2$ small additions of the other salts have considerable effect upon the growth. Although the increases in the amount of the salt added were very slight, they varied the lime-magnesia ratios considerably, and it is probable that for this reason they affected the growth markedly. (Pl. I.)

THE EFFECT OF VARIOUS RATIOS OF CALCIUM OXID TO MAGNESIUM OXID AT DIFFERENT CONCENTRATIONS.

The effect of five ratios of CaO to MgO (10 : 1, 5 : 1, 1 : 1, 1 : 5, and 1 : 10) were then tried. The $CaCl_2$ and $MgCl_2$ were present in such quantities that the amount of Cl_2 was constant in all the jars of a series, but the bases were present in the five different ratios. The effect of these ratios was tried at four different concentrations, where the Cl_2 from the $CaCl_2$ and $MgCl_2$ was present in 30, 40, 80, and 100 parts per 100,000. In the different series, then, the concentration of $CaCl_2+MgCl_2$ varied from 45.7 to 40.7, 61.6 to 54.3, 123 to 108.7, and 153.8 to 135.9 parts per 100,000, respectively. In all the series of different concentrations the other nutrient salts were present in the same amount, 44.2 parts per 100,000.



EFFECT ON RICE OF SMALL ADDITIONS OF MAGNESIUM CHLORID TO A SOLUTION CONTAINING MUCH CALCIUM CHLORID.

[No. 1, growing in solutions containing 90 parts $CaCl_2$ and 4.3 parts $MgCl_2$ per 100,000; No. 2, 90 parts $CaCl_2$ and 5 parts $MgCl_2$; No. 3, 90 parts $CaCl_2$ and 7 parts $MgCl_2$; and No. 4, 90 parts $CaCl_2$ and 10 parts $MgCl_2$ per 100,000.]

EFFECT ON RICE OF RATIOS OF LIME TO MAGNESIA IN DILUTE SOLUTIONS, CHLORIN FROM CALCIUM AND MAGNESIUM CHLORIDS CONSTANT. CALCIUM CHLORID 61.5 PARTS AND MAGNESIUM CHLORID 54.2 PARTS PER 100,000.

[No. 1, ratio of CaO to MgO, 10 to 1; No. 2, ratio 5 to 1; No. 3, ratio 1 to 1; No. 4, ratio 1 to 5; No. 5, ratio 1 to 10; No. 6, the check, contained 5 parts per 100,000 each of $CaCl_2$ and $MgCl_2$.]

The results are given in the following tables:

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2+MgCl_2$ 30 parts per 100,000. $CaCl_2+MgCl_2$ 45.7 to 40.7 parts per 100,000.]

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2+MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yields, taking that of ratio 1:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
40.7	5.0	45.7	89.9	10:1	14	12.15	2.11	0.63	2.74	94
36.7	8.8	45.5	89.7	5:1	16	13.12	2.25	.64	2.89	99
19.9	23.4	43.3	87.5	1:1	15	13.18	2.22	.69	2.91	100
5.9	35.2	41.1	85.3	1:5	15	12.07	2.04	.63	2.67	92
3.2	37.6	40.7	84.9	1:10	16	14.24	2.42	.70	3.12	107
5.0	5.0	10.0	54.2	....	16	14.96	2.44	.73	3.17	....

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2+MgCl_2$ 40 parts per 100,000. $CaCl_2+MgCl_2$ 61.6 to 54.3 parts per 100,000.]

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2+MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yields, taking that of ratio 1:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
55.0	6.6	61.6	105.8	10:1	16	15.73	2.55	0.88	3.43	97
49.0	11.7	60.7	104.9	5:1	15	15.86	2.57	.87	3.44	97
26.2	31.2	57.4	101.6	1:1	15	15.86	2.63	.90	3.53	100
7.9	47.0	54.9	99.1	1:5	16	17.08	2.53	.97	3.50	99
4.2	50.1	54.3	98.5	1:10	16	15.90	2.53	.92	3.45	98
5.0	5.0	10.0	54.2	....	16	22.50	3.44	1.20	4.64	....

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2+MgCl_2$ 80 parts per 100,000. $CaCl_2+MgCl_2$ 123 to 108.7 parts per 100,000.]

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2+MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yields, taking that of ratio 1:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
109.9	13.1	123.0	167.2	10:1	15	35.29	5.21	1.60	6.81	90
98.0	23.4	121.4	165.6	5:1	15	36.73	5.23	1.63	6.86	91
52.4	62.5	114.9	159.1	1:1	16	41.80	5.76	1.88	7.64	100
15.8	94.0	109.8	154.0	1:5	15	39.19	5.34	1.71	7.05	93
8.4	100.3	108.7	152.9	1:10	15	33.49	4.96	1.51	6.47	86
5.0	5.0	10.0	54.2	....	16	59.26	7.70	2.61	10.31	....

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2$+$MgCl_2$ 100 parts per 100,000. $CaCl_2$+$MgCl_2$ 153.8 to 135.9 parts per 100,000.]

Composition of solution.					Growth of plants.					
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2$+ $MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 16 alive at end of 40 days.	Green weight of tops.	Oven-dry weight of tops.	Oven-dry weight of roots.	Oven-dry weight of whole plant.	Relative yields, taking that of ratio 1:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	*Grams.*	
137.4	16.4	153.8	198.0	10:1	14	23.92	3.63	1.15	4.78	73
122.5	29.2	151.7	195.9	5:1	13	26.94	3.88	1.29	5.17	79
65.5	78.2	143.7	187.9	1:1	15	34.71	4.95	1.56	6.51	100
19.7	117.5	137.2	181.4	1:5	14	24.14	3.57	1.20	4.77	73
10.5	125.4	135.9	180.1	1:10	15	32.04	4.62	1.45	6.07	93
5.0	5.0	10.0	54.2	....	16	59.26	7.70	2.61	10.31	....

The results show that in the weaker solutions, containing 40.7 to 61.6 parts of the combined chlorids of calcium and magnesium, the ratio of the bases CaO and MgO had little or no effect upon the growth (Plate II). In the higher concentrations tried, however, the plants did much better where the bases were present in the ratio 1:1. The more concentrated the solution the greater was the difference between the ratio 1:1 and the other ratios.

It is apparent from the tables that the lime-magnesia ratio did not affect the proportion of the roots to tops at any of the concentrations tried.

THE EFFECT OF VARIOUS RATIOS OF CALCIUM OXID TO MAGNESIUM OXID AT DIFFERENT CONCENTRATIONS, WITH THE CHLORIN NOT CONSTANT.

The results are given below of four more experiments the data of which support those above. Through an error in using $CaCl_2 . 2H_2O$ instead of $CaCl_2 . 6H_2O$, which was not discovered until the plants were started, the following experiments are not exactly parallel to those above. In these experiments the ratios of CaO to MgO were 9:1, 4.5:1, 1.5:1, 1:2, and 1:4. The concentration of the sum of $CaCl_2$ and $MgCl_2$ also varies between different lots of the same series. In the four following series, then, we not only have the effect of different ratios of the bases but also of different concentrations of $CaCl_2 + MgCl_2$ and chlorin. The results are interesting, however, in showing how in concentrated solutions the lime-magnesia ratio has much more influence on the growth of rice than the absolute amount of the $CaCl_2$ and $MgCl_2$ or the chlorin.

The results of a series of experiments with small amounts of the chlorids are given below:

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2$+$MgCl_2$ 22.3–16.9 parts per 100,000. $CaCl_2$+$MgCl_2$ 34.3 to 23.1 parts per 100,000.]

Composition of solution.					Growth of plants.				
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2$+ $MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 12 alive at end of 50 days.	Green weight of tops.	Air-dry weight of tops.	Oven-dry weight of tops.	Relative yields, taking that of ratio 1.5:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	
30.3	4.0	34.3	78.5	9:1	12	19.39	3.88	3.06	101
25.5	6.8	32.3	76.5	4.5:1	12	18.51	3.58	2.81	93
15.6	12.4	28.1	72.3	1.5:1	12	20.99	3.89	3.02	100
7.3	17.3	24.6	68.8	1:2	12	20.83	3.90	2.99	99
4.0	19.2	23.1	67.3	1:4	12	20.92	3.96	3.02	100
6.9	4.3	11.1	55.3	....	12	24.08	4.58	3.43	....

It will be seen that where the $CaCl_2$ and $MgCl_2$ are present in 34.3 to 23.1 parts per 100,000 neither the variation in the concentrations between these limits nor the ratio between the bases affects the yield (Plate III).

In the table below are given the results with $CaCl_2$ and $MgCl_2$ varying between 68.7 and 46.3 parts per 100,000.

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2$+$MgCl_2$ 44.7–33.6 parts per 100,000. $CaCl_2$+$MgCl_2$ 68.7 to 46.3 parts per 100,000.]

Composition of solution.					Growth of plants.				
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2$+ $MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 12 alive at end of 50 days.	Green weight of tops.	Air-dry weight of tops.	Oven-dry weight of tops.	Relative yields, taking that of ratio 1.5:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	
60.7	8.0	68.7	112.9	9:1	12	14.40	3.04	2.48	98
51.5	13.6	64.7	108.9	4.5:1	12	15.70	3.19	2.57	101
31.3	24.9	56.1	100.3	1.5:1	12	15.60	3.15	2.54	100
14.5	34.6	49.1	93.3	1:2	12	16.93	3.41	2.78	109
8.0	38.3	46.3	90.5	1:4	12	17.50	3.44	2.80	110
6.9	4.3	11.1	55.3	....	12	22.81	4.30	3.52	....

It will be seen that the yield here increased slightly with the decrease in the total amount of these salts, and that the influence of the ratio of the bases was not apparent.

In the following table are given the results with $CaCl_2$ and $MgCl_2$ varying between 154.5 and 104.1 parts per 100,000.

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2+MgCl_2$ 106.6–75.6 parts per 100,000. $CaCl_2+MgCl_2$ 154.5 to 104.1 parts per 100,000.]

Composition of solution.					Growth of plants.				
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2+MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 12 alive at end of 50 days.	Green weight of tops.	Air-dry weight of tops.	Oven-dry weight of tops.	Relative yields, taking that of ratio 1.5:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	
136.5	18.0	154.5	198.7	9:1	2	1.53	.36	....	21
114.9	30.7	145.5	189.7	4.5:1	7	6.08	1.38	....	79
70.3	56.0	126.3	170.5	1.5:1	8	7.32	1.74	....	100
32.6	77.8	110.4	154.6	1:2	9	8.74	1.85	....	106
17.9	86.2	104.1	148.3	1:4	8	6.83	1.47	....	85
6.9	4.3	11.1	55.3	1.9:1	12	19.99	3.58	....	....

Here the yield of ratio 1.5:1 was far in excess of the ratios 9:1, 4.5:1, or 1:4. Since the total amount of the $CaCl_2$ and $MgCl_2$ in the series decreases from the ratio 9:1 to the ratio 1:4 we should expect the yield to increase regularly with the decrease in these salts, and thus be greatest at the ratio 1:4. In this concentrated solution, however, the influence of the ratio is stronger than the effect of differences in concentration and we have a marked depression in yield at the ratio 1:4.

The table below gives the results of a series with a still more concentrated solution, the $CaCl_2$ and $MgCl_2$ varying between 171.7 and 115.7 parts per 100,000.

Effect of different ratios of CaO to MgO.

[Cl_2 from $CaCl_2+MgCl_2$ 111.8–84 parts per 100,000. $CaCl_2+MgCl_2$ 171.7 to 115.7 parts per 100,000.]

Composition of solution.					Growth of plants.				
$CaCl_2$ in solution.	$MgCl_2$ in solution.	$CaCl_2+MgCl_2$ in solution.	Total salts in solution.	Ratio of CaO to MgO.	Number of plants of original 12 alive at end of 50 days.	Green weight of tops.	Air-dry weight of tops.	Oven-dry weight of tops.	Relative yields, taking that of ratio 1.5:1 as 100.
Parts per 100,000.	*Parts per 100,000.*	*Parts per 100,000.*	*Parts per 100,000.*			*Grams.*	*Grams.*	*Grams.*	
151.7	20.0	171.7	215.9	9:1	3	3.21	0.73	....	41
127.6	34.1	161.7	205.9	4.5:1	5	4.58	1.08	....	57
78.2	62.2	140.4	184.6	1.5:1	9	9.65	1.77	....	100
36.2	86.5	122.7	166.9	1:2	7	9.21	1.64	....	93
19.9	95.8	115.7	159.9	1:4	6	4.62	.94	....	53
6.9	4.3	11.1	55.3	....	12	18.00	4.17	....	....

EFFECT ON RICE OF RATIOS OF LIME TO MAGNESIA IN DILUTE SOLUTIONS, CHLORIN FROM CALCIUM AND MAGNESIUM CHLORIDS NOT CONSTANT AT DIFFERENT RATIOS. CALCIUM CHLORID 34.3 PARTS AND MAGNESIUM CHLORID 23.1 PARTS PER 100,000.

[No. 1, ratio of CaO to MgO, 9 to 1; No. 2, ratio 4.5 to 1; No. 3, ratio 1.5 to 1; No. 4, ratio 1 to 2; No. 5, ratio 1 to 4; No. 6, the check, contained 6.9 parts $CaCl_2$ and 4.3 parts $MgCl_2$ per 100,000.]

EFFECT ON RICE OF RATIOS OF LIME TO MAGNESIA IN CONCENTRATED SOLUTIONS, CHLORIN FROM CALCIUM AND MAGNESIUM CHLORIDS NOT CONSTANT AT DIFFERENT RATIOS. CALCIUM CHLORID 171.5 PARTS AND MAGNESIUM CHLORID 115.7 PARTS PER 100,000.

[No. 1, ratio of CaO to MgO, 9 to 1; No. 2, ratio 4.5 to 1; No. 3, ratio 1.5 to 1; No. 4, ratio 1 to 2; No. 5, ratio 1 to 1; No. 6, the check, contained 6.9 parts $CaCl_2$ and 4.3 parts $MgCl_2$ per 100,000.]

In this still more concentrated solution we have similar results to those in the preceding table, only here the effect of the ratio of the bases is yet more apparent. The large differences in concentration seem to have no effect on the yield compared with the effect of the ratio. Plate IV.

Considering the foregoing data, it is seen that in dilute solutions containing 34.3 to 23.1 parts per 100,000 of $CaCl_2$ and $MgCl_2$ neither the changes in concentration within these limits nor variations in the ratios of CaO to MgO between 9:1 and 1:4 have any effect on the yield. With the stronger solutions, containing 68.7 to 46.3 parts per 100,000 of $CaCl_2$ and $MgCl_2$ the yield increases regularly with the decrease in the amount of these salts, no effect of the ratio of CaO to MgO being apparent. In the concentrated solution containing 154.5 to 104.1 parts per 100,000 of $CaCl_2$ and $MgCl_2$ the effect of the ratio of CaO to MgO is stronger than the differences in the concentration. In the more concentrated solution containing 171.7 to 115.7 parts per 100,000 of $CaCl_2$ and $MgCl_2$ the effect of the ratio of CaO to MgO is still stronger.

These results agree with the data in the tables on pages 17 and 18 showing that the ratio of the bases lime and magnesia, at least within certain limits, appears to be without influence in dilute solutions, but that in concentrated solutions of $CaCl_2$ and $MgCl_2$ the ratio of CaO to MgO exerts a great influence on the growth of rice. The results also show that in concentrated solutions the ratio of CaO and MgO is of more importance than the absolute quantity of $CaCl_2$ and $MgCl_2$ or the amount of chlorin present.

SUMMARY OF RESULTS.

In the presence of a small amount of all the other nutrients equal percentage concentrations of $CaCl_2$ and $MgCl_2$ appear to be equal in their toxic action on rice. When compared on the basis of equivalent molecular quantities $CaCl_2$ is more toxic for rice than $MgCl_2$.

With a concentrated solution of $CaCl_2$, containing a minor quantity of the other nutrients, slight increases in the amount of $MgCl_2$ greatly improved the growth of rice. A like improvement was produced in concentrated solutions of $MgCl_2$ by small additions of $CaCl_2$.

In solutions of 172 to 109 parts per 100,000 of the combined chlorids of calcium and magnesium, all the other nutrients being present in minor quantity, the growth of rice was distinctly better when the bases, lime and magnesia, were present in the ratio 1:1, than in the ratio of 10:1, 5:1, 1:5, or 1:10. The favorable action of ratio 1:1 compared with other ratios was more apparent the more concentrated the solutions.

In the solutions of 62 to 23 parts per 100,000 of the combined chlorids, all the other nutrients being present, the growth of rice appeared to be unaffected by the ratio of lime to magnesia between ratios of 10:1 and 1:10.

DISCUSSION OF RESULTS.

The above work differs from previous work on the lime-magnesia ratio in using the chlorids instead of the nitrates or sulphates of these bases. The results of comparing the toxicity of $CaCl_2$ and $MgCl_2$ show that rice differs from many plants in being relatively less sensitive to $MgCl_2$.

The results of this work differ from similar studies on the lime-magnesia ratio in showing that, while the ratio appears to exert an action at comparatively high concentrations, it does not at low concentrations, at least not within the ratios tried. It is possible that at wider ratios than 10:1 and 1:10 an effect might have been observed even at low concentrations. The results show beyond doubt, however, that the effect of the ratio of lime to magnesia is much stronger at high concentrations of these salts than at low ones.[1]

In those cases where an antagonistic action of very dilute solutions of calcium and magnesium salts have been observed,[2] no other nutrients were present. Under such conditions there would be an antagonism apparent that would not occur where the solution is more nearly balanced. This is a point that has been overlooked by several investigators in drawing their conclusions regarding the toxicity of various ratios of salts. Because pure solutions of calcium and magnesium salts are toxic in certain ratios, even in dilute concentrations, it does not necessarily follow that these ratios are toxic in a complete nutrient solution where there are a variety of other salts present which may have an antagonistic action to magnesium and calcium. Osterhout[3] has shown that sodium acts antagonistically to both calcium and magnesium in overcoming their toxicity. Loew,[4] Lipman,[5] and B. Hansteen[6] have also noted an antagonism between potassium and magnesium. McCool[7] notes an antagonism between calcium and some eight other ions. In fact, it is evident from the experiments of

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[1] An analogous result was secured by R. H. True and W. J. Gies (Bul. Torrey Bot. Club, 30 (1903), p. 397). They found that by the addition of certain salts they could completely neutralize the toxicity of a copper salt; when, however, the concentration of copper was increased and the other salts left as before, the action of the copper was more slowly overcome, the poisonous activity of the copper being greater than could be neutralized by the amount of other salts present.

[2] True, R. H., and H. H. Bartlett, U. S. Dept. of Agr., Bur. Plant Indus. Bul. 231.

[3] Osterhout, Jahrb. Wiss. Bot. [Pringsheim], 46 (1908), p. 121.

[4] Loew, Bot. Gaz., 46 (1908), p. 302.

[5] Lipman, loc. cit.

[6] Hansteen, Jahrb. Wiss. Bot. [Pringsheim], 47 (1910), p. 289.

[7] McCool, loc. cit.

Loeb, W. Ostwald,[1] Osterhout,[2] and True and Gies[3] that, for plants and the lower forms of animal life, the more ions that are added to a pure salt solution the more the toxicity of the pure salt disappears.

It is evident, then, that an excess of any one salt would produce less injury in a complete nutrient solution than in a pure solution. The fact that even in a complete nutrient solution lime or magnesia may be toxic if present in sufficient excess of the other nutrients is also apparent from the work referred to, as in this case we approach more toward the conditions of a pure solution of lime or magnesia.

That it was found that the ratio of lime and magnesia was operative at high but not at low concentrations under the conditions of these experiments is to be explained as follows:

In the concentrated solutions of $CaCl_2$ and $MgCl_2$ (see tables, pp. 17, 18, and 20) we have the calcium and magnesium in excess of the other nutrients (potassium, sodium, iron, etc.)—an unbalanced condition. When we vary the ratio of CaO to MgO from 1:1 at these concentrations the solution becomes still more unbalanced. At the ratio CaO to MgO of 10:1, for instance, we have all the nutrients, including magnesium, present to a minor extent and the calcium present in a relatively great excess. When the ratio is 1:1, however, the balance of all the salts is less disturbed, no one being so greatly in excess, and the antagonistic action of the various bases becomes more effective. With the dilute solutions of $CaCl_2$ and $MgCl_2$ (see tables, pp. 17 and 19) neither the $CaCl_2$ nor the $MgCl_2$ within ratios of 10:1 to 1:10 is present in such excess that its toxic action can not be overcome by the combined action of all the other salts.

From this work it appears that we have to do not so much with the ratio of lime to magnesia as we have to do with the relation between whatever salt is in excess and all the other salts. That is, the question is not the simple one of a balancing of lime with magnesia, but a balancing of lime or magnesia with all the other nutrients. If the mere ratio in which lime and magnesia are present is the only factor operative, we should anticipate the yield to be affected by the ratio of these two salts in dilute as well as in concentrated solutions and independently of the other salts present. Such, however, was not found to be the case. The facts, then, seem to point to the following conclusions: The toxicity of an excess of lime or magnesia is not due simply to an unfavorable ratio between these two salts alone, but to an unfavorable proportion between the salt which is in excess and all the other salts present.

Now, in applying these results to soil conditions, it must be taken into consideration that in ordinary soils (alkali soils, of course,

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[1] Ostwald, Arch. Physiol. [Pflüger], 106 (1905), p. 568.
[2] Osterhout, Bot. Gaz., 42 (1906), p. 127; 44 (1907), p. 259.
[3] True and Gies, loc. cit.

excepted) the concentration of all the salts is exceedingly low; hence we should not expect the toxic action of any nutritive salt to become apparent unless it were greatly in excess of all the others. In the soil we also have a physical effect of the soil particles in diminishing the toxicity of any salt solution. This property of soils has been frequently observed and was well shown by Jensen [1] to be very effective in decreasing the toxic action of various salts and poisons on wheat.

It would seem, then, that the mere ratio in which the available lime and magnesia are present would be without effect in ordinary soils at least when present as chlorids. With alkali soils it appears, however, that the ratio of lime to magnesia may be of the utmost importance in determining the growth of plants.

The above conclusions are offered as the most reasonable deductions from the results obtained in this work coordinated with those of other investigators. They are offered as a limited contribution to an unsettled problem. It is realized that in these investigations only the chlorids of calcium and magnesium were tested and only one species of plant was used.

[1] Jensen, G. H., Bot. Gaz., 43 (1907), p. 11.

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